

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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Group Art Unit	2828
Examiner	GOLUB, Marcia A.
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Eye Safe High Power Fibre Laser	

RESPONSE TO OFFICE ACTION

To: Mail Stop Amendment
Commissioner for Patents
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This is responsive to the Office Action dated June 19, 2008.

Claim Summary:

Claims originally present: 1-31.
Claims previously canceled: 1-31, 32, 36-37, 42, 43, 45-46, 54 and 55.
Claims previously amended: 32, 33, 38, 40-42, 44, 47-51, 53.
Claims previously added: 32-71.
Claims hereby canceled: none.
Claims hereby withdrawn: 70 and 71.
Claims hereby amended: 63.
Claims hereby being added: none.
Claims remaining: 32-35, 38-42, 44, 47-53 and 55-67.



Amendments

Amendments to the Specification

Please replace the following paragraphs in the specification:

[0003] Traditional lasers used for material processing applications predominate at around 1.06 μm and longer wavelengths such as provided by a carbon dioxide laser (10.6 μm). These lasers are being supplemented by fibre lasers operating at around 1.06 μm . ~~1.06 μm .~~ Light scattered from the work piece when using such fibre lasers is a problem because the scatter is at wavelengths at which the retina of the eye can be easily damaged.

[0006] It is also preferable to use an optical ~~an optical~~-fibre material that has good heat resistance, low loss properties, and that can be fusion spliced.

[0018] The apparatus may be configured such that the optical radiation emitted by the first amplifying waveguide has a higher brightness when the second amplifying optical fibre emits at a first wavelength. This is a particularly advantageous implementation of the invention in that it is useful for modulating high-power fibre lasers that are pumped by a plurality of laser diodes. By high power, it is meant a fibre laser that emits greater than 10 W of ~~10 W~~ optical radiation, and preferably greater than 100 W. The invention is particularly advantageous for high power fibre lasers that emit between 1 kW and 10 kW of optical radiation. Instead of switching the laser



diodes on and off, the fibre laser can be controlled with a lower power signal. Advantages include increasing ~~increase~~ the life of the laser diodes, and removing the need for switching electrical power. Additionally, as will be described herein, the present invention allows distributed thermal management and shorter, more powerful lasers--particularly at so-called "eye-safe" wavelengths.

[0042] The invention is particularly useful for application in high power fibre lasers emitting optical radiation 15 between 1500 nm and 2500 nm. For example, if the first rare earth dopant 23 is erbium and the pump diodes 3 emit optical radiation at 976 nm, then the conventional solution for pumping the first amplifying fibre 20 would be to combine the optical radiation from the laser diodes 3 and couple the radiation into the first amplifying fibre 20. This approach is limited by the poor beam ~~beam~~-quality provided by the output of laser diodes. The conventional approach leads to large diameters of the first cladding 21 (for example 500 μ m ~~500 μ m~~ to 5 mm) and inefficient absorption of the pump radiation by the first amplifying fibre 20 which leads to undesirable heat generation. The inclusion of the intermediary stage involving the second amplifying fibre 30 permits brightness conversion. Thus the multimoded pump radiation emitted by the diode lasers 3 is converted to pump radiation having a higher beam quality in order to pump the first amplifying fibre 20. Thus for example, the second rare-earth dopant 33 may be erbium codoped with ytterbium, and pump radiation at a wavelength of 910 nm to 980 nm can be used to cladding pump the second amplifying fibre 30 whose second core 31 may be single mode (or multimode or contain a plurality of single mode or multimode cores) and be configured to emit



radiation at 1530 nm (or 1460 nm to 1550 nm). This is a convenient wavelength for in-band pumping the first rare ~~earth~~ ~~ear~~-dopant 23 (in this case erbium). It is then possible to reduce the cross-section of the first cladding 22 to smaller dimensions than would otherwise be possible, resulting in increased absorption and thus shorter fibre length. Advantageously, the invention also provides a method of distributing the thermal dissipation in several stages. This is particularly advantageous for providing high power (100 W to 10 kW) optical radiation 15 in the eye safe 1500 to 1650 wavelength window as the efficiency of cladding pumped erbium doped amplifiers can be relatively low (e.g., 25% to 30%) if pumped from 915 nm. The advantages combine to give an apparatus that is very advantageous for material processing applications where the control of thermal dissipation near the work piece and the eye safe wavelengths provide excellent safety advantages over existing systems.

[0043] Referring to FIG. 1, the apparatus 10 may include first reflectors 4 and second reflectors 5 in order to form a laser cavity in the second amplifying waveguide 2. The first and second reflectors 4, 5 may be mirrors, reflectors, gratings, or fibre Bragg gratings. If the second rare-earth dopant 33 is erbium codoped with ytterbium, then it is advantageous ~~its advantageous~~ to separate out the photosensitive region (typically doped with germania ~~germima~~) which is used to form the fibre Bragg grating from the region doped with the second rare-earth dopant 33 (which would require phosphorus co-doping). The second amplifying waveguide 2 may comprise a single core 31 which may be single moded or multimoded. Alternatively, the second amplifying waveguide 2 may comprise a plurality of cores 31 which may be single



moded or multimoded. A fibre amplifying optical fibre comprising multiple single mode cores is advantageous because it facilitates the writing of single-mode or multi-mode fibre Bragg gratings in each of the cores. Multiple cores containing fibre Bragg gratings offer a route towards high efficiency and shorter fibre lengths. Writing of the single mode fibre Bragg gratings is further facilitated by arranging the cores 21 linearly across the fibre's cross-section. The cores 21 can be spaced sufficiently far apart so as not to cause interference effects.

[0049] FIG. 6 shows apparatus comprising a plurality of the fibre pump sources 51 coupled into the first amplifying fibre 20 by side couplers 62. The side couplers can ~~take can taken~~ many forms known in the art for cladding pumping fibre amplifiers and lasers including the fibre arrangement 9 shown in Figs. 1 and 4.

[0057] FIG. 10 shows apparatus in which the wavelength of radiation emitted by the second amplifying waveguide 2 can be changed ~~hanged~~ by an actuator 101 attached to the second reflector 5 in first fibre pump module 102. The actuator 101 and second reflector 5 combination is a tuneable wavelength reflector which can be a grating that is thermally tuned or tuned by application of stress and/or strain. Thus for example, the second amplifying fibre 30 can be doped with ErYb and emit optical radiation normally at around 1 μm . If the first and second reflectors 4, 5 are selected to reflect in the wavelength range 1460 nm to 1550 nm, then by tuning the reflectivity of at least one of them (by wavelength and/or amplitude) such that both the first the ~~first~~ and second reflectors 4, 5 reflect at the same wavelength in the range 1460 nm



to 1550 nm, the second amplifying fibre 30 can be turned into a laser emitting at 1460 to 1550 nm. If the first amplifying fibre 20 is doped with Er then the erbium can be pumped in a manner that is controllable by the actuator 101. The second amplifying fibre 102 can contain reflectors 105, 106, which may be mirrors, gratings or fibre gratings configured such that apparatus 100 laser when pumped in the wavelength range 1460 nm to 1550 nm. This can be achieved if the reflectors 105, 106 reflect at longer wavelengths, say at 1560 nm.

[0058] An alternative means for changing the wavelength of radiation emitted by the second amplifying waveguide 2 is shown in FIG. 11. In FIG. 11, a source of radiation 111 is included in each first fibre ~~first fibre~~ pump module 112. The source of radiation 111 can be a laser that is controlled by application of a signal. Advantageously, the second amplifying waveguide 2 may contain ErYb dopant and the first fibre pump module 112 may be configured by first and second reflectors 4, 5 to emit radiation at 1090 nm. Preferably the first and second reflectors 4, 5 would have relatively low reflectivity (0.1% to 10%) in order to clamp the gain. This can be advantageous to prevent spontaneous pulses from damaging the apparatus. Injection of radiation in the wavelength range 1500 nm to 1550 nm by the source of radiation 111 (which may be a laser diode or fibre laser) of sufficient power level will cause the second amplifying fibre 30 to amplify the radiation and thus pump ~~pup~~ first amplifying fibre 20 (preferably doped with erbium) in order to emit the desired optical radiation 15. Thus control of the source of radiation 111 can be used to modulate the optical



radiation 15 which is beneficial for many high power laser applications because it avoids modulating the laser diodes 3.

[0060] In general the second amplifying fibre 30 in FIGS. 10 and 11 can be designed such that it can emit optical radiation at a first wavelength λ_1 or a second wavelength λ_2 in response to a signal (not shown ~~sown~~). The first amplifying fibre 20 is then designed such that the optical radiation 15 has a higher brightness when the second amplifying optical fibre 1 emits at ~~the fist~~ the first wavelength λ_1 than the second wavelength λ_2 . This is a particularly advantageous implementation of the invention, useful for modulating high-power fibre lasers that are pumped by a plurality of laser diodes. By high power, it is meant a fibre laser that emits greater than 10 W of optical radiation and preferably greater than 100 W. The invention is particularly advantageous for high power fibre lasers that emit between 1 kW and 10 kW of optical radiation. Instead of switching the laser diodes on and off, the fibre laser can be controlled with a lower power signal. Advantages include increasing the life of the laser diodes, and removing the need for switching electrical power. Additionally, as described in this specification, the invention allows distributed thermal management and shorter, more powerful lasers--particularly at so-called "eye-safe" wavelengths.

(End of Amendments to the Specification.)

(Continued on next page.)



Amendments to the Drawings

Please replace sheet 3 (containing Figs. 10 and 11) of the drawings with the attached "Replacement Sheet".

(End of Amendments to the Drawings.)

(Continued on next page.)

